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Разработка режимов сублимационной сушки при атмосферном давлении фукуса пузырчатого, измельченного методом криоэкструзии

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Аннотация. Обеспечение полноценного сбалансированного питания населения достаточно давно является одной из важных проблем ряда стран. Большинство регионов России относятся к йододефицитным. Недостаток йода зачастую восполняется в рационе граждан употреблением ламинарии. К сожалению, другие водоросли, относящиеся к классу бурых (лат. *Phaeophyceae*), например, фукус пузырчатый, оказались незаслуженно лишены внимания учёных и пищевых технологов. Использование фукуса в пищевом рационе жителей Российской Федерации позволит обогатить блюда полным набором макро- и микроэлементов, рядом витаминов, пантотеновой, фолиевой и аминокислотами, клетчаткой, необходимой для нормального пищеварения. С учетом произрастания фукуса пузырчатого на мелководье Баренцева и Белого морей, его можно считать местным продуктом, необходимым для питания жителей Мурманской области. Фукус пузырчатый, как и другие водоросли, можно отнести к сезонным продуктам. Заготовка водорослевого сырья продолжается всего полтора-два месяца в году. Для круглогодичной поставки фукуса пузырчатого на стол жителей его необходимо хранить и перерабатывать. Сублимационная сушка любого вида представляется весьма перспективным способом переработки фукуса пузырчатого и других бурых водорослей. Сублимированные продукты сохраняют практически все полезные свойства сырья. Сублимационная сушка при атмосферном давлении – слабо изученный процесс, для которого практически отсутствует математический аппарат, позволяющий определять изменение характеристик сырья в ходе проведения процесса. Исследуемое сырье предварительно было заморожено и измельчено методом криоэкструзии. Определение влажности сырья производилось стандартным методом с использованием прибора ВЧМ (прибора Чижовой). Проведенный этап исследования позволил определить влияние длительности процесса сублимационной сушки при атмосферном давлении на влажность высушиваемого фукуса для диапазона температур от «минус» 24 до «минус» 18 ^{0}С. Математическая обработка экспериментальных результатов выполнена с применением программы DataFit версия 9.1. Полученное обобщенное уравнение позволит прогнозировать изменения влажности сырья, требуемой длительности процесса, режима работы технологического оборудования и, как следствие, сократить эксплуатационные затраты на оборудование.

Ключевые слова: фукус пузырчатый, сублимационная сушка при атмосферном давлении, криоэкструзия, влажность, длительность сушки

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FOOD SYSTEMS

Original article

Development of Freeze Drying Modes at Atmospheric Pressure of Bladderwrack Ground by Cryoextrusion

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Abstract. Ensuring the complete balanced nutrition of the population has long been one of the challenging problems in a number of countries. Most regions of Russia can be referred to iodine-deficient areas. The lack of iodine is often replenished by consuming laminaria. Unfortunately, other algae belonging to the class of brown algae (Phaeophyceae), for example, bladderwrack, were undeservedly neglected by scientists and food technologists. The use of fucus in the diet of the Russian Federation's residents will enrich dishes with a full range of macro- and microelements, a number of vitamins, pantothenic, folic and amino acids, fiber essential for normal digestion. Provided that the growth of bladderwrack is in the shallow waters of the Barents and White Seas, it can be considered a local product needed for the nutrition of the Murmansk region inhabitants. Bladderwrack, like other algae, can be attributed to seasonal products. Harvesting of algal raw materials lasts only one and a half to two months a year. For a year-round supply of bladderwrack to the residents' diets, it has to be stored and processed. Any method of freeze-drying seems to be a promising way to process bladderwrack and other brown algae. Freeze-dried products retain almost all the useful properties of raw materials. Freeze drying at atmospheric pressure is a poorly studied process. For this method there is almost no mathematical apparatus making it possible to determine the change in the characteristics of raw materials during freeze drying. The raw material under study was previously frozen and ground by cryoextrusion. Determining the moisture content of the raw material was carried out by the standard method using the VChM device (Chizhova's instrument). The conducted stage of the study allowed determining the duration impact of freeze drying at atmospheric pressure on the moisture content of the dried bladderwrack at the temperature range from "minus" 24 to "minus" 180C. Mathematical processing of the experimental results was done using the DataFit version 9.1 program. The obtained generalized equation allows predicting changes in the moisture content of the raw material, the required duration of the process, the mode of operation of the process equipment and, as a result, reduce the operating costs of the equipment.

Keywords: bladderwrack, freeze drying at atmospheric pressure, cryoextrusion, moisture, drying time

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Introduction

For many decades, the problem of iodine deficiency has been solved in Russia, among other things, by adding laminaria to food, so the latter is a widely known alga [15].

Unlike laminaria, bladderwrack, abundant in the northern seas, has been neglected by researchers and food technologists. Laminaria and bladderwrack are different types of brown algae. Both are useful, nutritious, have a pronounced anti-aging effect, but differ in the percentage of useful components.

Bladderwrack or fucus (Fucus vesiculosus) refers to brown algae and has an unusual structure. The general view of bladderwrack is shown in Figure 1.

Fig. 1. Bladderwrack (Fucus vesiculosus) [6]

According to the results of many-year study of the research group of biochemistry and technology of aquatic organisms of the Murmansk Marine Biological Institute (MMBI) RAS under the supervision of E. Obluchinskaya, fucus of the Barents Sea is “the leader in the content of fucoidan and polyphenols among other types of brown algae, as well as representatives of the same species from other seas” [14]. Fucus from the Barents Sea is the least contaminated with metals, which means “less toxic than representatives of the same species from other seas of the Arctic”, therefore “it is better than others for the pharmaceutical industry as a source of biologically active substances” [14].

Fucus contains a complete set of macro- and microelements, many vitamins, pantothenic, folic and amino acids, polysaccharide fractions, fiber needed for the normal functioning of the gastrointestinal tract [6].

Fucus fucoidin is considered a reserve nutrient instead of laminarin. Its content is very small, but fucus fucoidans are widely used in biologically active additives and extracts of antitumor, immunomodulatory, antibacterial, antiviral and anti-inflammatory therapy and preventive measures, in cosmetology for body wraps, the manufacture of anti-aging creams, shampoos, as a natural pigment in cosmetics [14].

The seaweed contains iodine (1/2 teaspoon - 1 g) - from 30 to 80% of the required daily intake, considering the partial digestibility of iodine in accordance with the Technical Regulations of the Customs Union TR TS 022/2011 Food products in terms of their labeling (as amended on September 14, 2018) [17].

Fucus is used for food purposes, preferably as a laxative [14]. Difficulties in using this seaweed for food purposes arise due to the presence of anti-nutrients-substances that prevent trace elements, vitamins and nutrients from being absorbed.

Fucus is good at regulating appetite since it contains alginic acid with the gelling properties and the ability to swell 25-35 times in the stomach when water is absorbed. The enterosorption effect of

alginic acid provides its radioprotective and detoxifying effect, including the removal of heavy metals (lead, mercury, radionuclides) from the body [6].

In the food industry, bladderwrack is used in blends with other aromatic plants as a seasoning for hot dishes and salads.

The article presents the results of freeze drying of bladderwrack, ground by cryoextrusion, at two levels of negative temperatures under natural air convection. The presented results correspond to the end of the succeeding stage of the study on the development of rational modes of drying the algae under the specified conditions.

Materials and Methods

At this stage, the purpose of the study is to develop a mathematical model for changing the moisture content of the dried raw material depending on the time of the drying process at various negative temperatures.

Bladderwrack (Fucus vesiculosus) of the Fucus family (Fucales), harvested in August-September from 2018 to 2022 in the Dalne-Zelenetskaya Bay of the Barents Sea in the Eastern Murman was used as an object of study.

The subject of the study is the change in the moisture content in algae under various drying regimes.

The objectives of the study were to analyze the impact of various factors on the removal of moisture from the algal raw materials in the drying process.

To conduct the study, the raw material was preliminarily prepared: washed, laid out on a drain, then frozen, ground by cryoextrusion at a temperature of minus 18 0C using an extruder grinder. Its design was developed at the Murmansk State Technical University [8] using the matrix of “cone-cone” type (or "hourglass") 5.5\4.5\5.5 with a coefficient of the geometric shape of the holes 0.062635 cm3 [9, 11].

The experiment was planned according to the method of Latin squares [16]. The drying temperature was changed in steps of 60C and amounted to "minus" 180C and "minus" 24 0C. At the next stage of the study, it is expected to carry out freeze-drying at a temperature of minus 30 0C. For this purpose, the experimental unit is being modernized.

The experimental unit is designed on the basis of a refrigerator. The volume of the drying chamber is 125 dm3. The temperature was monitored using a K-type thermocouple operating with an M 838 multimeter.

The prepared raw material was placed on a baking sheet 10 mm thick.

The samples of the raw materials were taken regularly, every three days. The initial and residual moisture content of the dried product was determined using a VChM device (Chizhova's instrument) [10].

The processing of the obtained results was carried out by the method of non-linear regression using the DataFit v 9.1 program. The adequacy of the mathematical model was determined by the Fisher criterion (F-criterion) and the coefficient of determination (R2), the significance of each regression coefficient was determined by the Student's criterion (t-criterion) [2].

Results

In the course of the experimental studies, two stages of raw material processing were identified [4], they are shown in Figure 2:

1) The first stage of freeze-drying at atmospheric pressure and the temperature investigated;

2) Secondary drying under natural convection at a temperature of 12 ^{0}C.

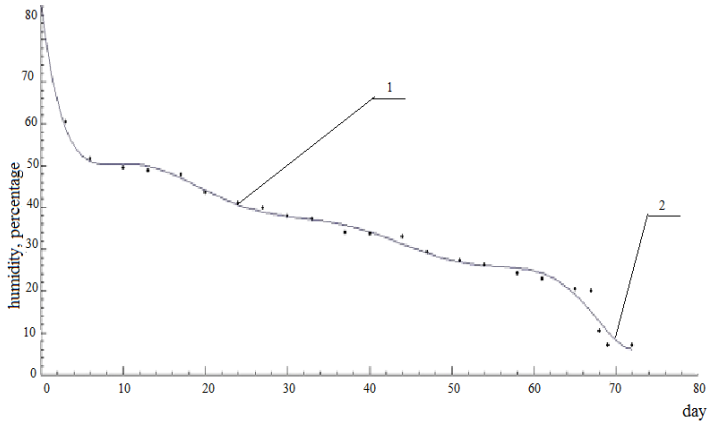

Fig. 2. Stages of freeze-drying at atmospheric pressure and temperature of "minus" 24 ^{0}C of fucus, gound by cryoextrusion. Compiled by the authors

A graphical summary of the experimental data results is shown in Figure 3.

The graphs clearly show the highest rate of the moisture removal in the initial period of drying, when free and mechanically bound moisture is actively removed. The increase in the duration of drying at different temperatures is explained by the increase in the initial moisture content of the raw material in drying at a temperature of minus 24^{0}C.

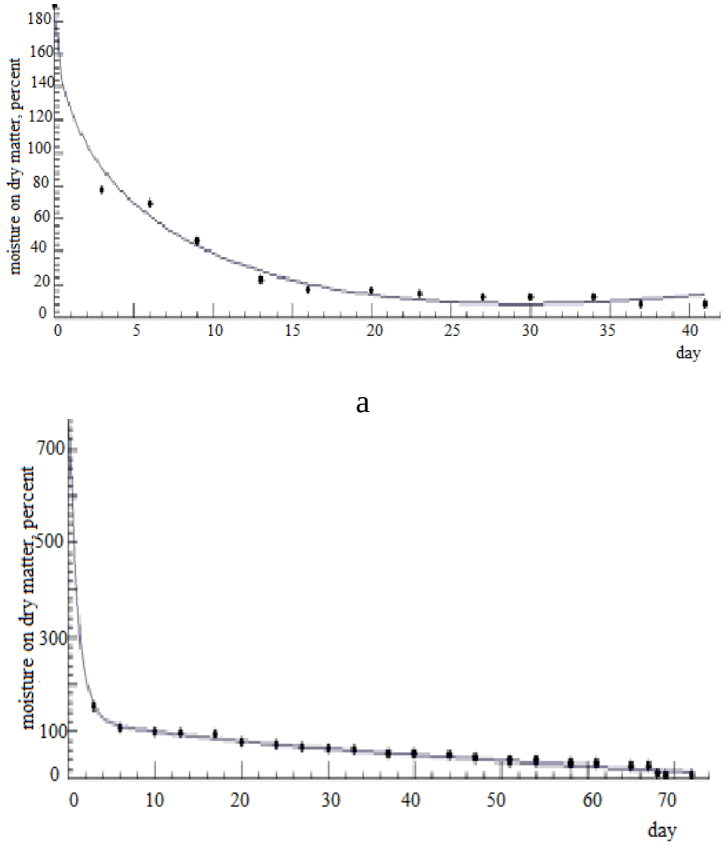

Fig. 3. Change in the moisture content of fucus in conversion to dry matter, depending on the duration of the drying process: a) at a temperature of "minus" 18^{0}C, b) at a temperature of "minus" 24^{0}C. Compiled by the authors

The result of this stage of the study was a generalized mathematical model that determines the dependence of moisture on dry matter of fucus freeze-dried at atmospheric pressure, ground by cryoextrusion, for various negative temperatures, expressed by the formula (1)

$$y = a + b \cdot x + c \cdot x^{0,5} + d \cdot e^{-x}, \quad (1)$$

where y is the moisture per dry matter, percentage;

x – duration of drying, days;

a, b, c, d – the coefficients of the equation presented in Table.

Coefficients for the equation (1). Compiled by the authors

Parameter	Parameter Value	Coefficient				Validity of the model	
		a	b	c	d	F-criterion	R^2
Temperature of drying, ^{0}C	«minus» 18	185,14	6,02	-65,24	0	393,79	0,98
	«minus» 24	149,78	0	-15,91	624,66	12656,27	0,99
Note–F_{tbl}-citerion (table value of the Fisher criterion) = 161.45 at a significance level of 0.05 [5]. All coefficients of the equation for each option are significant.							

Discussion

Freeze-drying at atmospheric pressure is one of the poorly studied methods of low-temperature processing of food, preferably vegetable, raw materials. In contrast, vacuum freeze drying is widely used for heat treatment of raw materials of both plant and animal origin [1,3,7,12,13,18].

Freeze-drying at atmospheric pressure is performed using refrigerators of various temperature ranges and does not require special additional equipment, while the quality of freeze-dried products is maintained. Its main disadvantage is a long duration of the process [10].

The study is carried out within the framework of R&D 5.03/21 "Improving the efficiency of technological processes and equipment in the Arctic region" [No. GR 121102500124-9].

Conclusion

In the course of the study, the equation that allows determining the moisture content of fucus, ground by cryoextrusion at a temperature of minus 180C was developed, depending on the duration of freeze drying at atmospheric pressure.

In formula (1), the coefficient "c" has a “minus” sign and causes a decrease in the moisture content of the raw material in conversion to dry matter, depending on the duration of the drying process. All other coefficients of the specified equation have a “plus” sign and lead to an increase in the value of the function.

The resulting mathematical model can be used for predictive calculation of the moisture content of raw materials, the required duration of the process, the mode of the technological equipment operation and, as a result, lead to the reduced costs of the unit performance.

The analysis of the problem and the results obtained conclude that the main areas of studying the process of freeze-drying at atmospheric pressure are aimed at reducing the time of drying and increasing the energy efficiency of the process.

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